Toward Portable Warm-Vapor Quantum Receivers: Concept, Benchmarks, and Applications

Authors

Prof. Dr. Md. Faridul Islam Chowdhury, MBBS, MS (Neurosurgery)
Neurosurgeon | Neuroscientist | Theoretical Cosmologist
Inventor of the Tanfarid Quantum Thermodynamic Universe (TQTU)
Founder & Director, Tanfarid Vision Research Institute
Bogura, Bangladesh
ORCID: 0000-0003-3178-0671

Abstract

We outline a conceptual design for a portable quantum receiver that leverages a warm alkali-vapor medium to store single-photon qubits. The proposed architecture integrates an electro-optic stage for feed-forward Pauli corrections and uses a single-photon detection module for readout. This receiver is designed for a quantum network where classical information, encoded at the single-photon level, is the payload. We present a normalized performance envelope and define an operational fidelity threshold to guide engineering and verification of these compact, room-temperature links. This perspective clarifies the necessary architecture, interfaces, and acceptance tests required for near-term demonstrations.

Keywords: quantum memory, warm vapor, feed-forward, single-photon detection, portable quantum links

1. Introduction

The development of quantum receivers capable of storing, correcting, and detecting photonic qubits is a critical step toward the realization of scalable quantum networks. While most experimental demonstrations have been confined to complex laboratory environments, there is a growing need for portable, field-deployable architectures. We propose a simple, room-temperature receiver concept that prioritizes fast feed-forward processing and the detection of single-photon qubits. This paper articulates the high-level architecture, defines the necessary interfaces, and provides a set of normalized, dimensionless metrics for performance evaluation and acceptance testing, without disclosing specific implementation details.

2. Proposed Architecture

The conceptual design of the quantum receiver consists of four primary functional blocks integrated into a compact system.

- **Qubit Preparation:** The system accepts a polarization-encoded single-photon-level input in the near-infrared, tuned to an alkali D-line transition band.
- **Warm-Vapor Memory:** A warm alkali-vapor cell provides a medium for quantum memory. It utilizes a Λ-type EIT or Raman process to achieve microsecond-scale storage duration, allowing time for classical feed-forward control signals.
- **Electro-optic Stage:** An integrated electro-optic modulator implements fast Pauli corrections (I,X,Z,XZ) on the retrieved qubit. The correction is selected based on a two-bit classical control signal received from an external channel.
- **Detection:** A single-photon detector reads out the qubit after it passes through a polarization analysis and spectral filtering stage.

The receiver exposes optical input/output interfaces, a classical control API for the two correction bits, and monitoring hooks for tracking key parameters such as photon counts, timing, and temperature. Implementation-specific details, including material choices, optical wavelengths, drive levels, and vendor part numbers, are intentionally withheld.

3. Demonstration Methodology

We propose a two-stage verification path to validate the receiver's functionality and performance.

- **Stage A (Software/Bench Emulation):** This phase involves simulating the receiver's behavior using an 8-qubit software simulator and benchtop polarization optics. The performance is evaluated based on normalized fidelities and timing margins.
- **Stage B (Hardware-in-the-Loop):** This phase involves the physical integration of the receiver's functional blocks. Acceptance tests include verifying storage-retrieve visibility, compliance with the Pauli truth-table, and successful round-trip transmission of information using repetition coding.

All performance metrics are reported as dimensionless or normalized values to maintain the focus on the architectural concept while withholding proprietary operating points.

4. Performance Envelope (Normalized)

The following metrics are proposed to benchmark the receiver's performance:

- **Fidelity vs. Temperature:** The operational fidelity $F(T)$ of the quantum memory is measured as a function of temperature. A key benchmark is the point $T*$ at which $F/F_{max} = 0.90$.
- **Latency Budget:** The classical control signal must arrive before the stored qubit decays. This is reported as a ratio of the classical latency to the qubit storage dwell time. A target value is a ratio less than 0.3.
- **Detector Signal-to-Noise Ratio (SNR):** This is measured by the ratio of photon counts to the square root of the dark counts, $SNR = counts/dark$.

- **Memory Efficiency:** The quantum memory's efficiency is measured by the ratio of retrieved photons to stored photons.

5. Conclusion

This paper presents a conceptual design for a portable, room-temperature quantum receiver using a warm alkali-vapor medium. By defining a clear architecture, specifying normalized performance benchmarks, and outlining a two-stage demonstration methodology, we provide a blueprint for a near-term, practical quantum communication device. This work is a step toward making quantum receivers a reality beyond the confines of a laboratory.